International Journal of Mechanical Engineering and Technology (IJMET)
Volume 6, Issue 12, Dec 2015, pp. 73-80, Article ID: IJMET_06_12_008
Available online at
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=6&IType=12
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

METAL HYDRIDE BASED COOLING SYSTEMS

Rahul K. Menon
Department of Mechanical Engineering, Maharashtra Institute of Technology,
Pune, Maharashtra, India

ABSTRACT

In recent years, a lot of attention has been directed towards metal hydrides. The reason being their ability to store hydrogen. Many attempts have been made to develop metal hydride based heating and cooling systems. The possibility to utilize low temperature heat (waste heat) to drive these systems has great potential, helping to reduce to pollution if implemented. Major applications are seen in air conditioning and heat supply for buildings and in air conditioning of automobiles. Although this technology offers the possibility to increase the energy efficiency of a car (by utilizing waste heat) and consequently reduces the CO2 emissions, its weight specific cooling power has so far been the main obstacle for an automotive application .In this paper, an overview of the operating principles and working of metal hydride based cooling systems; together with the material characteristics relevant to efficient operation of such devices are discussed.

Key words: Air-Conditioning, Metal Hydride, PCT, Sorption, Thermal Cooling

Cite this Article: Rahul K. Menon. Metal Hydride Based Cooling Systems, *International Journal of Mechanical Engineering and Technology*, 6(12), 2015, pp. 73-80.
http://www.iaeme.com/currentissue.asp?JType=IJMET&VType=6&IType=12

1. INTRODUCTION

Prices for energy supply have seen a steady increase over the years. This along with the expected global warming are heavily discussed issues about our future energy system and its economic and ecological price. The constant economic growth of industrial and especially of developing countries combined with the fast increasing population in these areas are crucial facts that increase the necessity for a rational use of all available forms of energy. Increased energy efficiency could tackle national emission or consumption targets without fearing the loss or reduction of living and comfort standards.

Also there were two main drawbacks with the existing system:

- The mobile air conditioning system is not completely leak tight and the refrigerant emissions cause pollution and global warming on a large scale.
- The compression of refrigerant vapor demands mechanical energy from the engine and consequently increases the overall fuel consumption along with the corresponding CO_2 emissions of the vehicle.

The general operation principle of metal hydride based sorption system is a closed operation cycle that utilizes hydrogen as working fluid. The underlying principle is the thermally driven compression of the working fluid (hydrogen) and its reaction with the metal hydride at different pressure.

2. METAL HYDRIDES

Metal hydrides are metals which have been bonded to hydrogen to form a new compound. Generally the bond is covalent in nature, but some hydrides are formed from ionic bonds. It is the combination of a metal lattice with a hydrogen molecule. Many kinds of metals or alloys can react reversibly with a large amount of hydrogen under certain conditions. The products of the forward reaction are called metal hydrides (MH), and the reaction can be written as;

$$M_{solid} + x/2\ H_{2\,gas} \leftrightarrow MH_{x\,solid} + heat$$

The chemical reaction of hydrogen and metal powder to form a metal hydride is given by the overall equation where M denotes any kind of metal or alloy able to absorb hydrogen (H_2), MH_x the corresponding metal hydride and ΔH the enthalpy of the reaction. It can be regarded as a reversible process and according to the principle of Le Chatelier-Braun, a pressure increase shifts the equilibrium to the right (hydrogen is absorbed), whereas a temperature increase shifts it to the left. A release of hydrogen (desorption) from the metal hydride is therefore possible by either reducing the hydrogen pressure or increasing the temperature. As the hydrogen absorption is generally exothermic, the endothermic desorption tends to cool the metal powder.

The MH materials have widely attracted attention since the successful development of some members with great potential for hydrogen storage, such as $LaNi_5$, TiFe and Mg_2Ni. Moreover, after years of study, the applications of MH have been much extended.

e.g. separation/purification of gas mixtures with hydrogen isotopes , heat pumping from low to high temperature , periodical heat storage and the thermal compression of hydrogen . Generally the MH related applications share the common advantages of being environmentally benign, compact and flexible for various operating conditions.

Metal hydrides (MH) possess several superiorities to other hydrogen storage media in several aspects such as safety and compact storage. Metal hydrides display very high volumetric storage densities, typically 100 to 120 grams of hydrogen per liter. A lot of heat is released during hydrogen absorption process, whereas much heat is absorbed during hydrogen desorption process. A continuous cycle of adsorption and desorption is used to provide the required cooling.

The stability (dissociation pressure) of the metal hydride phase is one important issue for its applicability. Technically relevant pressure and temperature conditions of the metal-hydrogen reaction depend on the desired application but can be typically assumed as $p \approx 1 - 100$ bar and $T \approx 240 - 750$ K, respectively.

2.1. Mechanism of H2 movement through the metal crystal lattice

The H2 molecule is first weakly physisorbed on the surface and the chemisorbed as strongly bound, individual H-atoms. The size of the hydrogen atoms is lighter and smaller than the metal atoms; therefore, they diffuse quickly from the surface into the periodic sites in the metal crystal lattice

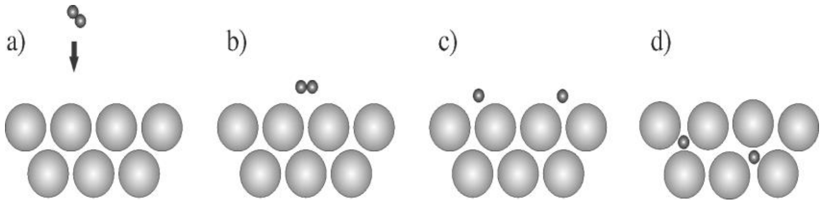

Figure 1 Movement of hydrogen molecules

2.2. Selection of Alloys

The performance of the MH systems largely depends on the properties of the metal hydrides selected. They should have high COPs and high specific power outputs, i.e. in case of refrigerator air-conditioner, specific cooling power (SCP). They should be compact in design, i.e. low mass and/or low volume, have a long life and low performance degradation, and they should be economic. Therefore, metal hydrides used for MHHCS should respectively have suitable properties, e.g. high enthalpy of formation, low specific heat, and high hydrogen absorption capacity, fast reaction kinetics, favorable equilibrium pressures, low hysteresis, flat plateau, simple activation process, minimum degradation after cyclic operation, low cost, etc. There is a plethora of metal hydrides which are potentially suitable.

2.3. Preparation

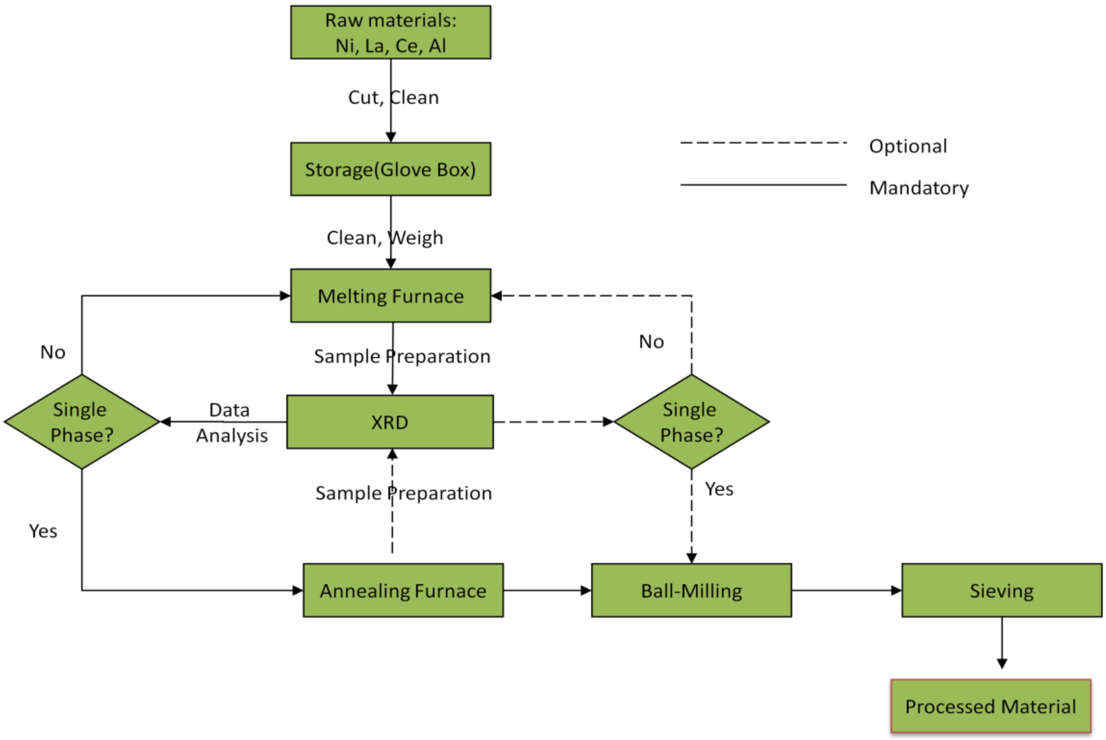

Figure 2 Preparation of Metal Hydride alloys

3. PRESSURE COMPOSITION TEMPERATURE (PCT) PROFILES

PCT measurements of available alloys are necessarily the first steps of a sorption system design as they reveal the metal hydride properties that consequently define the working conditions of the system. Even though experimental data are available for a variety of metal hydride alloys, a detailed examination of the respective metal hydride characteristics is important. Especially hysteresis, plateau pressure and slope depend on the compositions of the used misch metal (= Mm, mainly Cr and La) or the respective production processes and are only to a certain extent predictable.

Basically, PCT is determined by keeping an alloy sample at constant temperature and measuring the pressure change as hydrogen is absorbed. The hydride/dehydride cycling causes a change of the inter-metallic compounds volume that cause cracking for the particles. This cracking of the particles cause increasing of the surface area, which leads to an increase of the hydrogen reactivity

Most metal have high attraction for hydrogen and there are also few have poor attraction for hydrogen and the reaction between the metal and hydrogen can be exothermic or endothermic respectively. The process of absorption and desorption is best illustrated by the pressure composition-temperature profiles (PCT curves)

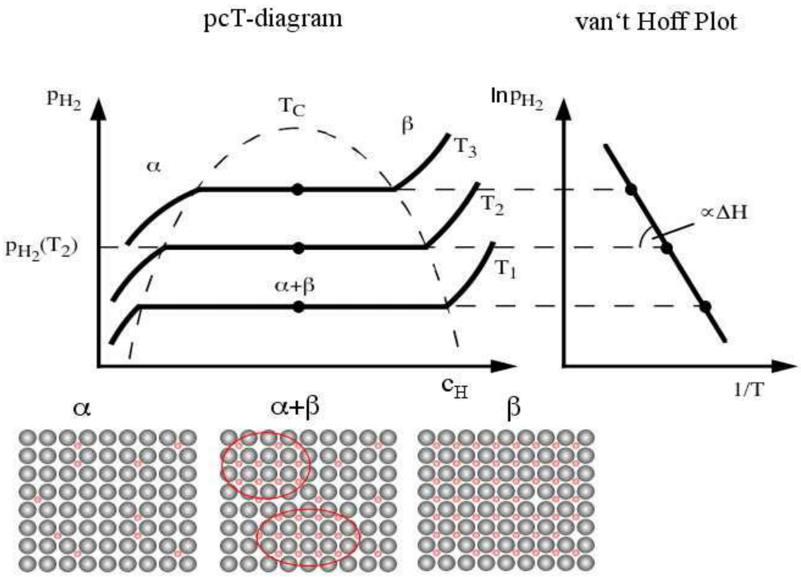

Figure 3 Sample PCT diagram of a metal hydride

There are three important parameters that can be obtained from a PCI measurement:-

- Effective storage capacity for storage systems.
- Hysteresis, which is an important characteristic. The hysteresis should be as low as possible as it reduces the efficiency of the system.
- Plateau slope, which is the equilibrium pressure in the middle of the plateau.

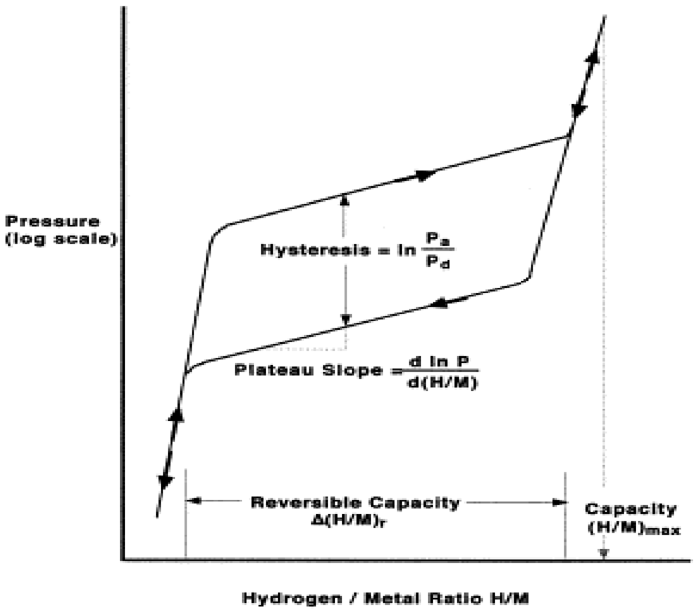

Figure 4 PCT parameters depicted

Thermodynamic behavior of metal hydride formation is illustrated in the figure, which is a PCT curve. The line of the upper pressure represents the absorption process and the lower line represents the desorption process and the flat part of both lines is called Plateau. And the difference in equilibrium pressures between the absorption and desorption reactions is called Hysteresis.

4. SORPTION COOLING SYSTEM CONFIGURATION

Theoretically, it is possible to develop a large number of different schemes for sorption cooling systems. However, practical considerations like pressure and temperature levels, internal heat and mass exchange area, cost and properties of the working fluids limit the number of practically feasible schemes. A typical configuration is described here:

The system comprises of reactors with metal hydrides A and B. There are particular properties of metal hydrides of A and B which are very important. Let us consider A1, A2 to be HT (High temperature) reactors or regeneration alloys and B1, B2 to be LT (Low temperature) reactors or refrigeration alloys. A1 and A2 are filled with metal hydride A while B1 and B2 are filled with metal hydride B. The major difference between the HT and LT reactors is that HT reactors absorb hydrogen at room temperatures and desorbs at high temperatures while LT reactors absorb hydrogen at room temperatures and desorbs at low temperatures.

In practice a heat recovery of about 40% is possible. Cooling temperatures of 10°C to -50°C can be obtained with the single stage system.

5. WORKING

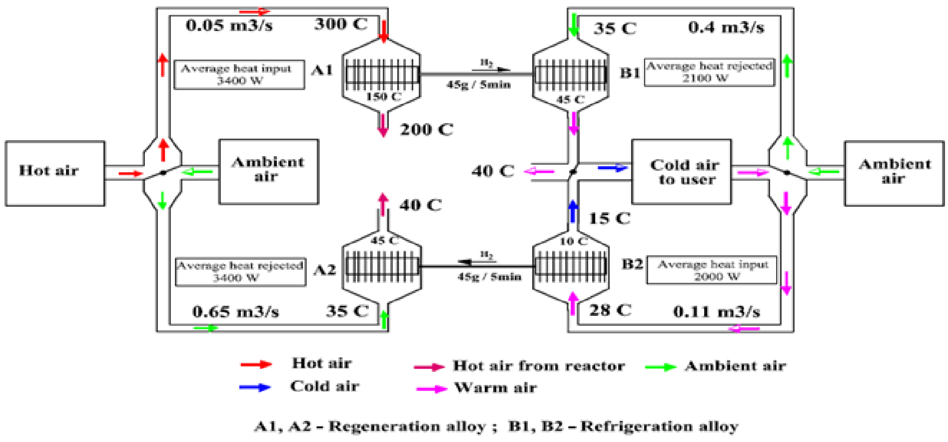

Figure 5 Process flow diagram of first half cycle

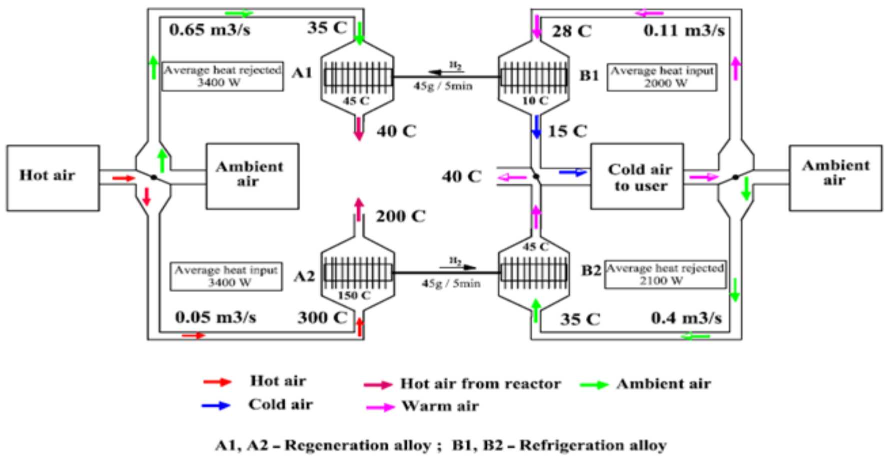

Figure 6 Process flow diagram of second half cycle

- There are two types of reactors: HT(High temperature) and LT (Low temperature)
- The reactors are made to undergo a process known as activation which involves infusing hydrogen in the reactors.
- HT reactors absorb hydrogen at room temperatures and desorbs at high temperatures.
- LT reactors absorb at room temperatures and desorbs at low temperatures.
- Hot exhaust is passed to the HT reactor and the reactor desorbs hydrogen gas.
- The gas travels to the LT reactor and ambient air is passed.
- The LT reactor absorbs the hydrogen in an exothermic reaction.
- This process continues until there is a concentration difference between the HT and LT reactor.
- In the next half cycle ambient air is passed to the LT reactor and the reactor desorbs hydrogen gas in an endothermic reaction.
- During this process the temperature of the air is reduced and is passed on to the user.
- The hydrogen travels back to the HT reactor which absorbs the hydrogen in the presence of ambient air.

- This process continues until there is a concentration difference between the HT and LT reactor.
- In the next half cycle the reactors are interchanged. These two cycles are repeated over and over to provide the necessary cooling

6. ADVANTAGES

- Improved fuel efficiency
- Proper utilization of a waste commodity and turning it into something useful.
- Traditional refrigerants can be avoided.
- Less pollution and hence reduced global warming.
- Decreases carbon footprint of vehicles.
- Hydrogen is a renewable source of energy; hence we don’t have to worry about its depletion.

7. CONCLUSION

Metal hydrides are promising working materials for thermally driven solid sorption cooling machines with hydrogen as working fluid. The systems can cover a wide range of operating temperatures from cryogenic applications to comfort air conditioning. A variety of heat sources from solar heat to automobile exhaust gases can be used to drive the cooling systems. In recent years various designs of such machines have been successfully demonstrated on a laboratory model or prototype scales. In fact, these can be most appropriate for small capacity portable or mobile cooling applications.

REFERENCES

[1] P.Muthukumar,M.Groll; Erratum to “Metal hydride based heating and cooling systems: A review”;International Journal of Hydrogen Energy 35 (2010) 3817-3831

[2] Feng Win,Jiangping Chen,Manqi Lu,Zhiju Chen, Yimin Zhou,Ke Yang ;”Development of a metal hydride refrigeration system as an exhaust gas-driven automobile air conditioner”;Renewable Energy 32 (2007)

[3] Marc Linder;”Automotive Cooling Systems based on Metal Hydrides”; Institute of Nuclear Technology and Energy Systems, University of Stuttgart,2010

[4] J.Paya,M.Linder,E.Laurien,J.M.Corberan;”Dynamic model and experimental results of a thermally driven metal hydride cooling system”;International Journal of Hydrogen Energy 34 (2009) 3173-3184

[5] Ch.Veeraju, M.Ram Gopal; “ Heat and mass transfer studies on plate fin-and-elliptical tube metal hydride reactors”; Applied Thermal Engineering 30 (2010)

[6] Fusheng Yang, Zaoxiao Zhang;” Simulation Studies on the Coupling Process of Heat/Mass Transfer in a Metal Hydride Reactor”; Xi’an Jiaotong University,P.R.China M. Chandra Sekhar Reddy., Thermal Analysis of A Heat Sink For Electronics Cooling, *International Journal of Mechanical Engineering and Technology*, 6(11), 2015, pp. 145 - 153

[7] F.S. Yang,G.X.Wang,Z.X.Zhang,X.Y.Meng, V.Rudolph;” Design of the metal hydride reactors- A review on the key technical issues”; International Journal of Hydrogen Energy 35 (2010) 3832-3840

[8] F.Laurencelle,J.Goyette; " Simulation of heat transfer in a metal hydride reactor with aluminium foam"; International Journal of Hydrogen Energy 32 (2007) 2957-2964

[9] Zewei Bao,Fusheng Yang,Zhen Wu,Serge Nyallang Nyamsi,Zaoxiao Zhang;" Optimal design of metal hydride reactors based on CFD-Taguchi combined method"; Energy Conversion and Management 65 (2013)

[10] Giridhara Babu Y., Ashok Babu T.P., Anbalagan M. and Meena R., Experimental and Numerical Investigation of Adiabatic Film Cooling Effectiveness Over The Compound Angled Gas Turbine Blade Leading Edge Model, *International Journal of Mechanical Engineering and Technology*, 5(9), 2014, pp. 91-100.

[11] Groll,M., H.-P.Klein and S.Srinivasa Murthy;" Metal Hydride based Thermal Systems: A Review"; World Renewable Energy Congress -VII; Cologne, Germany, 29 June- 5 July, 2002.

[12] Kapil Chopra, Dinesh Jain, Tushar Chandana, Evaluation of Existing Cooling Systems For Reducing Cooling Power Consumption, *International Journal of Mechanical Engineering and Technology*, 3(2), 2012, pp. 210 - 216.